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CLOUD TOP ANALYSIS USING CLOUD MODEL SIMULATIONS AND SATELLITE OBSERVATIONS

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1. INTRODUCTION

A central issue in the study of impact of convective systems related to strong phenomena is the understanding of their complex structure and evolution. Such systems are often related to high precipitation rate, strong winds and hailfall. Satellite observations and cloud microphysical model (CMM) simulations have proven to be effective in the study of this kind of phenomena. These two approaches, even different, complement themselves in the description of convection, providing an observative approach joins with a theoretical one.

A peculiar characteristic of cloud top of deep convective system has been defined as Enhanced-V or V-Shape; different studies have been performed so far to describe and explain this feature (e.g. Heymsfield et al, 1983ab). McCann (1983) accumulated V statistics from half-hourly enhanced IR data from April to July 1979. He found that storms with a V pattern had about 70% probability of producing severe weather, and that the median lead time from the onset of the V to the first severe weather was about 30 minutes. Adler et al. (1985) also presented similar evidence that the V feature is correlated with reported severe weather. They found that 75% of storms with the V feature had severe weather, but 45% of severe storm examined did not have this feature.

Different studies have been previously performed making use of satellite data, radar observations, conventional data and, in few cases, of numerical model simulations. Among them, Heymsfield and Blackmer (1988) treated in the more complete way this subject, also proposing a conceptual model to describe the phenomenon. But, for used numerical models, it was difficult to reproduce all observed features. This was mainly due to the lack of ice processes inside the model microphysics (Schlesinger, 1984, 1988).

Now that improvement in satellite technology, model refinement and computational resources get observational and simulation approaches to have almost the same spatial resolution, with reasonable computational time, a complete combined study is feasible.

The aim of this work is to merge satellite and numerical model approaches in the study of some features related to cloud top structure. An approach that considers both satellite observations and cloud three dimensional microphysical model simulations seems to be a good way in order to learn more about physics of convective systems and to improve image interpretation significance.

To perform this study two events have been selected, from their intensity, the availability of data on which compare satellite derived parameters and their previous model simulations. These events have been observed by geostationary and polar platforms and simulated by Wisconsin Dynamical-Microphysical Model (WISCDYMM).

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2. PREVIOUS STUDIES ON ENHANCED V

2.1 *Satellite approach*

For almost ten years across eighties, different studies making use of satellite data have been focused on the V-Shape study and analysis; this was mainly due to the facility to detect this feature from the first infrared (IR) geostationary satellite data.

Heymsfield and Blackmer (1988) performed a complete analysis on satellite observation of V-Shape feature. Most of the terms used in analyzing IR data are shown in Figure 1. The cold area (CA) is a region of embedded low equivalent black body temperature (EBBT) associated with the convective updrafts and top of the storms. CA is typically at the vertex of the V. The close-in warm area (CWA) is defined as an embedded region of higher temperature ≤50 Km downwind of the cold area. Often the CWA has a distinct EBBT maximum, although sometimes is only a degree warmer than the overall anvil temperatures. The Distant Warm Area (DWA) is defied similarly to the CWA, except it is further downwind. Usually DWAs are more transient than the CWAs and often do not have a maximum of EBBT.

A notable classification was made by Adler and Mack (1986); they indicated that thunderstorms with thermal couplet (CA and CWA) might be classified according to three types of thunderstorm tops:

Class1: the IR coldest point is located with the cloud top and there is no close-in warm point;

Class 2: similar to Class 1 except a warm point exists downwind of the cloud top.

Class 3: cold and warm points exist and with the cold point displaced upstream of the cloud summit.

They found that thunderstorms could go through the three storm top classes during their lifetime.

2.2 *CMM simulations*

Some cloud microphysical models have been tested in order to reproduce and study the dynamical Mack (1986) made numerical calculation using one

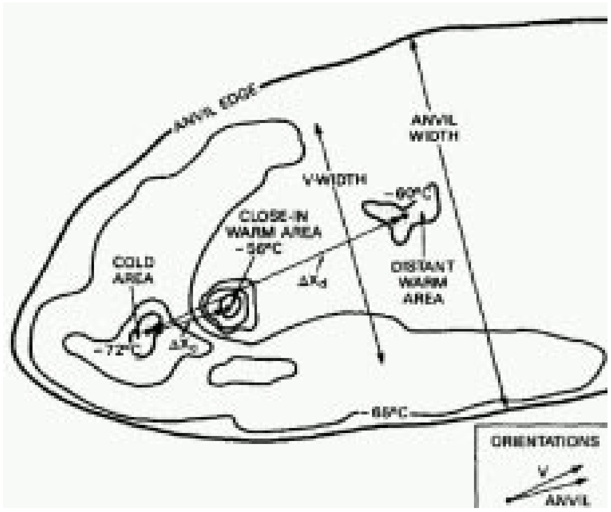


Figure 1: Terminology for cloud top features based on 23:34 UTC 2 May 1979 GOES IR image (Heymsfield and Blackmer, 1988).

processes involved in V-Shape formation. Adler and dimensional cloud model to simulate the overshooting cloud top. Their approach was based on a one-dimensional parcel model (Schlesinger, 1984). They concluded that the warm point occurs due to the subsistence and overshooting on the downward side; moreover they said that cirrus observed above the anvil (Fujita 1982) is an effect of this process, not the cause of the distinct warm point.

Schlesinger (1984, 1988) used a three-dimensional cloud model without ice processes to examine origins of air in the cold and warm points. The resulting cloud top analysis reproduced both thermal couplet and V (U) shape of the cold area; the V-Shape was found to be parallel to the cloud top horizontal wind field and cloud-top height/temperature was found consistent with Adler and Mack class 2 and class 3 systems. Moreover class 3 systems looked favored by marked stratospheric inversion, while class 2 looked favored by no stratospheric inversion.

3. DATA AND ALGORITHMS

Two events have been selected accounting for their evolution, previous simulations and available data amount. One of them had already been studied (analyzed and simulated, see Lin 2000), while the other has been selected because of its evolution and the high quality of available satellite data. Table 1 describes event specifics, available simulations and data.

Table 1. Data availability for selected events

Event Location	Date	Data available
Montana (CCOPE project)	8/2/1981	Simulation, GOES-4
Nashville (TN)	5/25/2000	Simulation, GOES-8, MODIS

The observational dataset for the CCOPE event consists of GOES-4 images in both Visible and Infrared spectra, starting at 21:45 UTC of 8/2/81 to 04:15 of 8/3/81. The time resolution is 30 minutes, while spatial resolution for infrared images is about 4x7 Km.

The observational dataset for the second event consists of GOES-8 images (channels 1, 2, 3, 4, 5) from 23:00 UTC of 5/24/00 to 08:00 UTC of 5/25/00, with temporal resolution from 15 to 3 minutes and spatial resolution from 1x1 Km (ch. 1) to 2x4 Km (others), and MODIS overpass at 04:30 UTC, with spatial resolution from 250 m (bands 1 and 2) to 1 Km (bands 8-36).

The microphysical model used in this work is a reviewed version of the WISCDYMM model developed in 1989 (Starka, 1989). The theoretical framework of the WISCDYMM is a non-hydrostatic, three dimensional, time-dependent cloud model. The WISCDYMM utilizes six different types of water substance: water vapor, cloud droplets, cloud ice crystals, rain drops, snow, crystals and aggregates and graupel/hail. There are a total of 38 microphysical processes incorporated in the model including nucleation, condensation, evaporation, freezing, melting,

For this study the hail parameterization model (HPM) version of the WISCDYMM, (inverse exponential size distributions for rain, snow and graupel/hail, and monodispersed distributions for cloud water and cloud ice) has been used (see Straka 1989 for a complete description).

A compromise between simulations definition (spatial and temporal) and computational resources, sets spatial resolution at 1 km, and temporal resolution at 2 minutes. A horizontal grid spacing of 1 Km and vertical spacing of 0.5 Km over 20 Km depth and over a 56x56 Km horizontal domain is found to adequately resolve the dynamics of all storms here analyzed (there are 8 to 12 grid points across the main features of the cloud in the CCOPE storm).

4. RESULTS

4.1 ***CCOPE Case***

In order to identify cloud top on cloud model output, three substances have been considered and analyzed: Relative Humidity respect to ice (RHi), snow content (qs) and ice content (qi). A graphical comparison has shown that 90% RHi is the best field value to identify the cloud top. Temperature field has been considered over this iso-surface above 8 Km level.

A 3 dimensional animation of the evolution of this surface showed a well defined cold V-Shape pattern, with a warm area downwind. As for Adler and Mack class 3 systems, the cloud top coldest point is displaced respect to the highest one. Horizontal distances vary from 0 Km to 6 Km during evolution. Sometimes there is superposition between them. Height differences range from 0 Km to 3.5 Km. These differences are more evident in the first part of the event evolution, while in the final part (steady state and dissipation) points tend to be closer in height. There are no preferred displacement directions: the relative position of coldest point respect to the highest point is spread around the highest one during the event evolution. This is in contrast to what observed by Adler and Mack about class 3 systems, which observed coldest point downstream respect to the highest point.

A further analysis was performed comparing coldest point and warm area values and their relative positions. The warm area maxima range from 223 K to 229 K (maxima inside a warm pool), and distances between CAs and CWAs vary from 1.4 to 20 Km. Warm areas are always located downwind respect to the coldest point. The almost constant CWA value is in good agreement with that observed by Heymsfield and Blackmer even though values are a little bit warmer (around –45 C) than observed before (-56 to –60 C). CA evolution has a variation rate (up to 16 degrees) larger than observed by Heymsfield and Blackmer (10 degrees). Distances retrieved by model analysis resulted shorter than observed by Heymsfield and Blackmer using satellite data (lower than 20 Km compared with 21-44 Km), but larger than values simulated by Schlesinger (up to 10 Km)

Satellite analysis involved EBBT field. IR 11 μm images show, at the early stage (21:45 UTC) a growing cell with a warm area inside a cold cloud top. This structure went to a V-Shaped cold area in the following images (22:15, 22:45). A cold minimum grew in the southern arm, becoming the coldest point at 23:45. After that, the V-Shape feature was present till 00:45, but the coldest point wasn't located on the vertex. After 00:45 it became more like a cold ring around a warm inner area, and after 2:15, no warm areas could be identified on the EBBT field.

Comparison between simulated and observed CWAs shows very similar values, while CA analysis suffers of the coarse satellite resolution: simulated values are generally 10 K colder than observed ones, with a peak of 18 K at 2:15 UTC. Despite to these differences, the trend of both curves is almost the same, showing a good agreement in the cold point genesis. Distances report almost the same problem as CA points: in fact the trend is almost the same in observations and simulations, but with different magnitude.

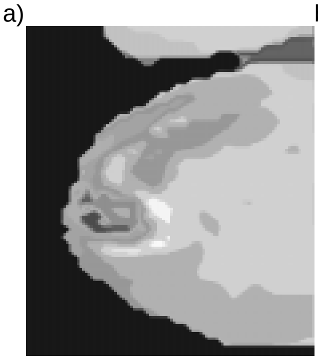
4.2 ***Nashville Case***

A complete analysis using simulations and observations has been made on this event. A detailed analysis comparing GOES 8 and MODIS quasi-simultaneous observations has been made as well. Moreover, even though current event is not directly related to CCOPE case, these two events have certain common characteristics which worth to be analyzed. First, they both show a well-developed V-Shape feature, second their spatial dimension is comparable (around 30 Km linear dimension of updraft area and around 120 Km anvil area) as well as temporal evolution (around 4 hours); at last they show very peculiar feature on cloud top simulation and observation. Comparison between their lifetime as seen by simulation of CCOPE case and observations (GOES and MODIS) of Nashville case shows high similarity between the evolution of these two events. Cold and warm patterns can be identified on both observations and simulation; shapes and dimensions are similar as well as their duration. Moreover, the availability of MODIS and GOES data almost at the same time allows evaluating how the spatial resolution improvement affects the cloud top observation. Figure 2 shows the most complete instant we have in term of data availability: GOES images (channel 4, 4:32 UTC, remapped onto MODIS high-resolution grid is shown in figure 2 a)) and MODIS data (band 31, 4:30 UTC, figure 2 b)). Computed synchronization gave model output results after 90 minutes simulation (see figure 2 c)). In MODIS image it's easy to identify a well-developed cold V shaped area (dark area). There are two coldest areas: the biggest one is close to the V vertex, while the second smaller cold area is located toward the system center. Due to its lower resolution, GOES image shows a V-Shape structure but cannot identify this second cold point.

MODIS image describes in a great detail both cold and warm areas. Warm area is placed between the V arms, with two warmer areas deeply penetrating in the inner part of the cold vertex area just around the smallest minimum. This behavior is in great accord to that showed by cloud model simulation: a cold “tongue” extended from the V vertex to the center of the system surrounded by a warm 'U' shaped area.

a)

b)



c)

Figure 2. a): GOES-8 11 μm EBBT field colder than 235 K at 04:32 UTC of May 25 2000. b): MODIS 11 μm EBBT image for 4:30 UTC. c): cloud model output: temperature field plotted over cloud top as identified by 90% RHi isosurface (90 min. simulation X-Y view of CCOPE case).

CA and CWA points identified on model outputs are generally warmer than CA and CWA in EBBT satellite pictures. CA differences range from 0.3 to 10 degree, while CWA differences are more similar around 17 degrees (from 15 to 19 degrees). Moreover, MODIS observation for 4:30 UTC shows a CWA quite close to GOES observation while CA value is colder than GOES value of about 11.6 degrees (199.5 K GOES EBBT, 187.9 K MODIS EBBT). This, in accord to that observed by Negri (1982), comes from different sensor spatial resolutions: even though GOES channel 4 resolution is about 2 by 4 Km, MODIS band 31 resolution is 1 by 1 Km. This means that in one GOES pixel there are 8 MODIS pixels and this accounts for more than 10 K EBBT difference. Distances are generally shorter in model outputs respect to satellite observations (in both GOES and MODIS observations). Distances are closer at the early stages but the more the system develops the more the distances in GOES observations grow. This could be due to the coarse resolution as well, since closer warm areas in model output are generally too small to be detected by geostationary satellites.

6. CONCLUSIONS

The cloud top structure proposed by Heymsfield and Blackmer (1988) has been observed in all two cases. Even if distant warm areas have not been investigated, CAs and CWAs have been found in both observations and simulations. Their evolution has been found consistent to which proposed by previous studies. The high resolution of both of them (observations and simulations) has provided a detailed description of the cloud top area just above the updraft. Some new features have been identified in cloud model simulation and seen in high-resolution satellite observations as well.

Model simulations have been run, analyzed and some interesting conclusions have been carried out. The high spatial (1 Km) and temporal (2 minutes in this case) resolutions have enabled to study simulated cases in great detail. The most notable observed characteristics are related to the 'U' shape of the closest warm area and a second minimum that appears downwind respect to the cold V vertex. The 'U' shaped warm area showed peculiar characteristics: two maxima placed over the 'arms', and penetration on the colder part just around a cold tongue. The second cold point has been found located at the end of this cold tongue, extended downwind from the V vertex.

Newer satellite-borne sensors provided better spatial, temporal and spectral resolution respect previous studies. Moreover, among them (GOES-4, GOES-8 and MODIS) improvement due to better resolutions could be clearly evaluated. Cloud top features identified by CMM analysis cannot be observed in GOES-4 images (resolution around 4x7 Km) and in GOES-8 images (2x4 Km), while they are clearly present on MODIS images (1x1 Km resolution). Even if we cannot be sure that a better resolution could see something more than GOES-4 images, for the GOES-8 case we can see the improvement of cloud top features identification provided by MODIS data (see figure 2). In this case a comparison between cloud simulations and MODIS 11 μm channel shows a very similar pattern for both cold and warm area, confirming the high quality of model simulation processes, satellite sensor and selected approach.

6. ACKNOWLEDGEMENTS

This work has been funded in part by a fellowship provided by University of Ferrara, “Ufficio Programmazione e Sviluppo”, “Borse di Studio di Perfezionamento all’Estero”.

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